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METHOD AND APPARATUS FOR ALLOCATING A PILOT SIGNAL ADAPTED TO THE CHANNEL CHARACTERISTICS

## TECHNICAL FIELD

The present invention relates generally to wireless multi-carrier communications systems and in particular to resource allocation and pilot signals of such systems.

## BACKGROUND

In most wireless systems, e.g. GSM (Global System for Mobile communications), WCDMA (Wideband Code Division Multiple Access), WLAN (Wireless Local Area Network), special well known training sequences or pilot signals are transmitted so that the receiver can estimate the channel parameters sufficiently well for detection of any data signal, not previously known by the receiver. Several methods exist to do this, some use user specific pilots and some use common pilots or combinations. Some pilots are code spread and overlaid with user data, others have dedicated time-frequency slots when pilots are transmitted. In any case, some part of the available radio resources must be allocated for pilots resulting in overhead that cannot be used for data.

In single-carrier systems, such as e.g. described in US 6,452,936, pilot data can be provided in certain time slots within a transmission frame. A shorter time interval between successive pilot data gives a more accurate channel estimation, but decreases instead the transmission rate. In US 6,452,936, a particular code of the CDMA system is allocated to a user. A pilot density of a frame structure is continuously selected dependent on channel estimation information.

A multi-carrier approach has been proposed in wireless communications systems, in which a data stream typically is separated into a series of parallel data streams, each of which is modulated and simultaneously transmitted

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with a different frequency. An example of a multi-carrier system is an OFDM (Orthogonal Frequency Division Multiplexing) system. This allows a relative size of transmitted symbols relative to a multipath delay to be much larger which reduces intersymbol interference. Such a cellular multi-user, multi-carrier wireless communications system thus allows a particular user to utilise more than one carrier simultaneously. The allocation of one or several carriers depends typically on quality of service consideration, such as requested transmission rate. Generally, in a multi-carrier, multi-user system, the resource space is used in a flexible manner to give each user the best possible quality at each time. The principles and requirements for providing channel estimations become in this way more complex than in a single-carrier system, since a continuously use of a single communication resource is not ensured. In a cellular multi-user, multi-carrier wireless communications system, the base station must accommodate many users that each experiences different channel characteristics due to fading in both time and frequency. Furthermore, different users travel at different speeds and thus experience different Doppler shifts.

Today, there are a few multi-carrier systems in use. However, they are not particularly designed for the difficult, ever changing, hard-to-predict multi-user environments that are envisioned for future wireless systems.

For example, the systems for DVB/DAB (Digital Video Broadcasting/Digital Audio Broadcasting) are broadcast systems that cannot take into account the need for individual users. Such systems must design their pilot structure according to the worst-case scenario so that detection becomes possible even under the worst possible conditions. Such a pilot structure gives rise to a substantial pilot overhead, and is indeed necessary in these worst-case scenarios. However, whenever the situation is better than the worst case, which typically is the case most of the time, the pilot structure is unnecessarily extensive, giving an unnecessary pilot overhead for most users. The pilot overhead can indeed be substantial. This reduces data

capacity in the own cell and furthermore increases the interference to the neighbouring cells (so called "pilot pollution").

Another example of a multi-carrier system is WLAN (i.e. IEEE 802.11a, IEEE 802.11g). Such a system is designed for a limited geographical area in which the users are stationary or slowly moving. The design is not intended for conditions in which the user is moving quickly or for handling mobility in a multi-cellular environment.

In the published US patent application 2003/0215021, a communications system is disclosed, in which channel characteristics are determined by analysing a signal received over a (sub)-carrier. The determined characteristics are then used to divide the sub-carriers into groups of similar fading characteristics. Each group is then allocated a pilot sub-carrier. The determined pilot allocation scheme is then used for future transmissions across the sub-carrier. This system compensates for differences in fading characteristics over the carrier bandwidth, but has a disadvantage in that it is assumed that a sub-carrier is continuously used for one single user. A user has to have access to a large number of sub-carriers in order to make such a pilot allocation efficient. Furthermore, entire sub-carriers are allocated as pilot sub-carriers, which occupies a large part of the available resource space, contributing to the pilot pollution.

## SUMMARY

The main problems with existing solutions are that pilot structures are either not at all suitable for considerably changing radio conditions or that they are designed for worst cases which in turn results in vast pilot overhead and "pilot pollution".

An objective of the present invention is to provide methods and devices for multi-user multi-carrier wireless communications system, which are capable to provide all users with sufficient pilots without causing unnecessary pilot

overhead and pilot pollution. A further objective of the present invention is to provide such methods and devices, which are easy to implement within present and planned wireless systems.

The above objectives are achieved by methods and devices according to the enclosed patent claims. In general words, a set of different pilot structures are designed for use in different environments and/or different general radio characteristics that are expected to occur in the cell. The radio conditions for a user are estimated, either from direct measurements or from knowledge about the cell characteristics, possibly combined with position information. Each user is then assigned an area in resource space for its communication, which has a suitable pilot configuration. In one embodiment, the entire resource space is provided with different pilot structures in different parts in advance and allocation of resources to the users are then performed in order to match estimated radio conditions to the provided pilot structure. In another embodiment, allocation is performed first, and then the actual pilot structure is adapted within the allocated resource space area to suit the environmental conditions. For best performance, depending on such things as frequency selectivity, time selectivity (e.g. time dispersion and Doppler shift), and path loss the amount of pilot energy should be adapted and the 'distance' between pilots in the time-frequency domain needs to be changed.

The radio resource space can have different dimensions. In multi-carrier systems, frequency is one dimension. Other dimensions that could be utilised within the present invention are time, code, antenna and/or spatial dimensions. One or several of these dimensions span the radio resource space, in which the present invention is applied.

By adapting the pilot structure to the environment or set of environments likely to occur in the cell and allocating these pilots to the users most likely to benefit from them, an overall efficiency is achieved. The amount of pilot overhead is then connected to the actual environments being accommodated.



Difficult environments require more overhead than simpler ones and hence pilot pollution is reduced on the average.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

The invention, together with further objects and advantages thereof, may best be understood by making reference to the following description taken together with the accompanying drawings, in which:

FIG. 1 is a schematic illustration of a multi-user wireless communication system;

FIGS. 2A and 2B are illustrations of pilot structures in time-frequency space, and the allocation of different users to subspaces;

FIG. 3A illustrates a radio resource space having a code dimension;

FIG. 3B is an illustration of a pilot structure in the frequency-code subspace;

FIG. 4 is a flow diagram illustrating an embodiment of a method according to the present invention;

FIGS. 5A, 5B and 6 are diagrams illustrating pilot structures in time-frequency space, and the allocation of different users to subspaces according to embodiments of the present invention;

FIGS. 7A and 7B are flow diagrams illustrating other embodiments of a method according to the present invention;

FIG. 8 is a flow diagram illustrating a part of a further embodiment of a method according to the present invention;

FIGS. 9A to 9C are block diagrams of downlink radio management devices of network nodes according to embodiments of the present invention;

FIG. 10 is a block diagram of uplink radio management devices of network nodes according to embodiments of the present invention;

FIG. 11 is a diagram illustrating pilot structures in time-frequency space having different intensities, and the allocation of different users to subspaces according to an embodiment of the present invention; and

FIGS. 12 and 13 are diagrams illustrating limited data descriptions of regular pilot structure.

## DETAILED DESCRIPTION

In the following description, OFDM (Orthogonal Frequency Division Multiplexing) systems are used for exemplifying the present invention. However, the present invention can also be applied to other multi-carrier wireless communications systems.

In the present disclosure, "pilots" refer to signals known by a receiver and therefore used for estimation purposes. "Data" refers to signals not previously known by the receiver, typically user data, control signals or broadcast information.

Fig. 1 illustrates a multi-user multi-carrier wireless communications system 10, in this particular embodiment intended to be an OFDM system. Non-exclusive examples of other communications systems, in which the present invention is advantageously applicable, are IFDMA (Interleaved Frequency Division Multiple Access) systems, non-orthogonal or bi-orthogonal multi-carrier systems. A base station or access point 20 communicates with two mobile stations or user equipments 30A, 30B. There is a downlink connection 22A between the access point 20 and the user equipment 30A and an uplink connection 24A between the same nodes. Likewise, there is a downlink connection 22B between the access point 20 and the user equipment 30B and an uplink connection 24B between the same nodes. User equipment 30A is located at a relatively large distance from the access point 20, but the speed 32A (illustrated as an arrow) of the user equipment 30A is small. User equipment 30b is located closer to the access point 20, but has a high speed 32B (also illustrated as an arrow). The user equipment 30A may have a relatively high need for repetitive pilots in the frequency dimension, since the propagation conditions for the different carriers may differ considerably over the bandwidth in case of multi-path propagation with large delay spread. However, the radio conditions are probably quite slowly varying with time due to the small speed of user equipment 30A. The user equipment 30B is

close to the access point, and a pilot on one frequency can probably be used for channel estimations for many neighbouring carriers. However, the radio conditions are probably changing rapidly in time, whereby frequent pilots in time dimension are required.

Fig. 2A is a diagram of a time-frequency space. This can represent a limited portion of the entire available radio resource space 100 in these two dimensions. Data is transmitted in quantities limited in time and frequency. These data quantities correspond to the small squares 104 in the diagram. Selected ones 102 of these data quantities contain pilot data and are illustrated in the diagram with hatching. The pilot structure in this embodiment is dispersed over the time-frequency space relatively uniformly. With this distribution, one data quantity out of 11 is occupied by pilot data. The useful data transmission rate is thereby reduced by  $1/11$ . The users of the user equipments 30A and 30B (Fig. 1) have allocated radio resources within the available radio resource space 100. User equipment 30A is allocated the resource sub-space indicated by 108A, while user equipment 30B is allocated the resource sub-space indicated by 108B. Both users are experiencing the same pilot density and the uniform distribution between the frequency and time dimensions.

User 30B moves fast. The time between two consecutive pilot messages in time dimension is 11 time slots, and even if information from neighbouring frequencies are used for channel estimation in the meantime, at least 4 time slots will pass between two consecutive updates. The speed of user 30B is so high that this pilot structure is not sufficient for an acceptable quality of service.

However, arranging the pilot structure as in Fig. 2B will change the situation. Here, there is a new update in time dimension every second time slot, which well supports the fast moving user equipment. Despite this increased density in time direction, the total amount of pilot data quantities

is reduced somewhat. Now only one data quantity out of 12 comprises a pilot. The overhead has decreased from 1/11 to 1/12 (about 9%).

However, user equipment 30A now achieves problems. This user equipment 30A moves slowly and is of limited use of the frequent updating in time. However, it has need for more closely located pilots in frequency dimension instead. The pilot structure of Fig. 2B becomes very unsuitable for user equipment 30A.

So far, only two dimensions, time and frequency, have been discussed. Fig. 3A illustrates a radio resource space in three dimensions, time, frequency and code. In such a system, each data quantity will instead correspond to a small cube 104. Generalisation can be performed to higher order spaces, comprising e.g. antenna or space dimensions. In general, any radio resource space in at least two dimensions, of which one is frequency, can be used with the present invention.

Fig. 3B illustrates a pilot pattern in a frequency-code space for a specified time. In this example 16 different codes are available and also 16 different frequencies. The illustrated pilot pattern leads to that the pilots are transmitted on all frequencies during the specified time duration, however, spread out in the code dimension. One code in each frequency is occupied by a pilot, whereas the remaining 15 codes are used for data transmission.

As mentioned briefly above, more generally the antenna or spatial dimensions could also be part of the resource space. One example is that different frequency bands are allocated to different beams of a multi-sector or fixed beam site. In this case, the spatial dimension is part of the description since different pilot patterns may be deployed for the different beams that overlap in the spatial domain. With the grouping of resources in terms of antenna sectors or beams the pilots allocated to different users can change dynamically when the user for example moves between sectors and the sectors have different frequency bands allocated to them. In such cases,



antenna or spatial dimension can also be used as additional dimensions in a total resource space.

The flow diagram of Fig. 4 illustrates the main steps of an embodiment of a method according to the present invention. The procedure starts in step 200. In step 202, a number of pilot configurations are provided, which are believed to suit different radio conditions appearing in the cell in question. At least two such pilot configurations are available, i.e. they can be handled by both sides of the transmission connection. At least one of the pilot configurations comprises sub-carriers having both pilot resources and data resources, i.e. resources allocated for any data not previously known by the receiver, such as user data, control signals or broadcast information, in order to accommodate efficiency requests from e.g. slow-moving terminals. The transmitter manages the sending of pilots according to this configurations and the receiver is capable of performing channel estimation based on the at least two pilot configurations. In step 204, an estimation of the radio conditions at the receiver is obtained. This estimation can be provided in many different ways. The actual radio conditions can be measured and evaluated. Another possibility is to assume an estimate from knowledge about the characteristics in the cell and possibly based on e.g. location and/or speed of the receiver relative the transmitter.

In step 206, a user is allocated resources in resource space, which have a pilot configuration that is matched to the estimated radio conditions. This matching can be performed in different manners, described more in detail further below. The procedure stops in step 299. Anyone skilled in the art realises that step 202 preferably is performed once, and the provided pilot structures can then be used for any future allocation of users, or re-allocation of existing users.

A few examples, using OFDM as an example system, will be used to visualise the effect of the present invention. The basic setup in Fig. 5A is assumed as follows. During a certain time period and seen over all frequency resources,

the available radio resources constitute a grid of basic resources that can be used for data, control signalling or pilot signals or other signals as discussed earlier. The resolution in frequency dimension is one OFDM carrier and in time it is one OFDM symbol. Pilot symbols are as above depicted with hatched boxes.

The transmitter side, in this example assumed to be the base station, determines a number of different pilot patterns and assigns these pilot patterns to different parts of the entire radio resource space. The pilot patterns may for example be periodically recurring with some period or pseudo-randomly designed. This means that different parts of the radio resource space have a denser or at least differing pilot pattern than other parts. Each pilot pattern is intended to accommodate users experiencing different channel characteristics.

This is illustrated in Fig. 5A. The entire radio resource space illustrated is divided into four rectangular parts, 110A-D. The resource space part 110A has a pilot pattern, having a dense occurrence in time dimension (every second OFDM symbol at certain carriers), but a more dispersed behaviour in the frequency dimension (only every sixth OFDM carrier). The resource space part 110B has a very diluted pilot pattern, having only one pilot in 36 resource units, evenly spread in time and frequency dimensions. The resource space part 110C is the opposite of part 110A, with a dense pilot pattern in frequency dimension, but sparse in time dimension. Finally, resource space part 110D has a very dense pilot structure in both dimensions, comprising a pilot symbol in every fourth resource unit.

According to one embodiment of the invention, the users are now allocated to the different parts of the radio resource space dependent on their estimated radio conditions. In other words, whenever a certain user has certain demands, the user is assigned resources in the resource space where pilots with the appropriate density can be utilised for channel estimation. In the situation in Fig. 5A, there are pilot structures suitable for typically four

combinations of Doppler and delay spread. In part 110A, the pilot structure is intended for a large Doppler and low delay spread. In part 110B, the pilot structure is intended for a low Doppler and low delay spread. In part 110C, the pilot structure is intended for a low Doppler and high delay spread. In part 110D, the pilot structure is intended for a high Doppler and high delay spread.

A first user, having radio conditions demanding a high density of pilots in both dimensions is allocated to the resource sub-space 108A within the part 110D. A second user, only having need for dense pilot in the time dimension is allocated resources in a resource sub-space 108B within the part 110A. A third user with very favourable radio conditions is allocated to a resource sub-space 108C in part 110B. Finally, two more users, having high demands on pilot density are given resources in two sub-spaces 108D and 108E, respectively in part 110D. One realises that each user has achieved a pilot pattern that is suited to its individual needs. It is beneficial, e.g. to assign resources for mobiles with certain fast varying channel or Doppler conditions in the dense parts of the pilot pattern and users with more slowly varying conditions in the less dense parts.

Note that the base station does not need to transmit all pilots at all times. Only pilots that in fact can be utilised by any user needs to be transmitted. If a pilot resource at time of transmission cannot be utilised by any data symbol that some user need to detect with the help of said pilot, then the pilot need not be transmitted. In such a way, the overall pilot pollution is reduced, and so is the average transmission power.

In Fig. 5B, a further embodiment of the present invention is illustrated. Assume the same situation as was present in Fig. 5A. Three users are occupying all resources in the densest part 110D. If yet another user with need for a very dense pilot configuration appears, the pre-defined pilot configuration plan of Fig. 5A becomes insufficient. However, the new user can be allocated to a free resource sub-space 108F, preferably in connection

with the part 110D. This sub-space 108F had originally a pilot pattern according to part 110C, but when allocating the user, the pilot pattern is adjusted to match the demands put by the new user. In such a way, the original pre-determined division into different parts in the resource space can be adapted to the actual need. However, if a good initial configuration is used, most cases are covered and the frequency of adjustments is low.

Now, return to the situation of Fig. 5A. If the user having the allocation of sub-space 108E slows down, the estimated radio conditions change, and the need for pilots is reduced. The user can then be reallocated to another sub-space of the resource space, having a more suitable pilot configuration for the new estimated radio conditions, e.g. to part 110C. An alternative is to keep the allocated sub-space but instead change the pilot pattern to a more suitable one for the new conditions.

The ideas of adjusting or adapting the pilot configuration when needed can also be brought to the extreme end, where no pilot pattern at all is pre-configured for the different parts of the resource space. Instead, there is always an adjustment of pilot pattern for all users. This is schematically illustrated in Fig. 6. Here, a first user was assigned a sub-space 108A, without associated pre-defined pilot pattern. The pilot pattern was then adjusted according to the actual needs as concluded from the estimated radio conditions. In this case a dense pattern was selected. A second user was allocated to sub-space 108B and subsequently, a suitable pilot pattern was selected for this sub-space. In such a way, all the sub-spaces 108A-F were associated with pilot configurations suitable for each individual need. Sub-spaces not allocated to any user do not comprise any pilots in such an approach. A user with certain estimated properties is thus allocated to use certain resources and the pilot pattern is designed accordingly. The result is the same as the previous embodiments, pilot patterns and user characteristics are matched.



The above embodiments can also be expressed in flow diagrams. In Fig. 7A, a flow diagram corresponding to the situation in Fig. 5A is illustrated. The resource space is in step 203 provided with at least two different pre-determined pilot configurations at different parts of the resource space. Step 204 is unchanged compared to Fig. 4. In step 207, the matching of the radio conditions and pilot structures is performed by selecting a suitable resource space.

The situation in Fig. 5B is illustrated by the flow diagram of Fig. 7B. Also here, pre-defined pilot configurations are associated with different parts of the resource space in step 203. In step 205, it is determined whether there is any available resources in parts that are suitable for the particular estimated radio conditions for the user to be allocated. If there are resources with suitable pilot structures available, the procedure continues to step 207, as in Fig. 7A. If no resource space with appropriate pilot structure is available, any free resource space is allocated in step 209, however, preferably in the vicinity of the part having a suitable pilot pattern. In step 210, the pilot configuration is adapted within the selected resource sub-space to match the estimated radio conditions.

The embodiment illustrated in Fig. 6 can similarly be illustrated by the part flow diagram of Fig. 8. Here, the step 206 in Fig. 4 is described in more detail. In step 208, an area is selected as a resource sub-space for the user. In step 210, the pilot configuration in the selected area is adapted to the need connected to the estimated radio conditions of the user. Note the similarities between Fig. 7B and Fig. 8.

The present invention can be implemented for wireless communication between any nodes in a communications system. Such nodes can be e.g. user equipment, mobile station, base station, access point or relay. In the examples below, the most straightforward situation with communication between a base station and a user equipment will be discussed as an

example. The scope of the claims should, however, not be affected by this example.

Multi-carrier communication is typically most applied in downlink connections. In Fig. 9A, a wireless communications system according to an embodiment of the present invention is illustrated. A base station 20 communicates with a mobile terminal 30 via an uplink 24 and a downlink 22 connection. In the downlink communication, the ideas of the present invention are implemented. The base station 20 comprises a downlink control unit 25, which is enlarged in the lower part of Fig. 9A. The downlink control unit 25 is responsible for allocating resources for communication on the downlink 22 between the base station 20 and the mobile terminal 30 and comprises in turn a pilot manager 26 and a radio condition processor 28. Similarly, the mobile terminal or user equipment 30 also comprises a downlink control unit 35, also enlarged in the lower part of Fig. 9A. The downlink control unit 35 comprises a channel estimator 36 and a measurement unit 38 for radio conditions.

The radio conditions measurement unit 38 measures the actual radio conditions at the user equipment 30. Such measurements can comprise e.g. Doppler shift and signal strength as well as power delay profile, channel impulse response, time and frequency selectivity measurements and interference levels. The results of the measurements are transferred to the radio conditions processor 28 of the base station 20, preferably by the uplink communication link 24. The radio conditions processor 28 evaluates the measured conditions and translates it to estimated radio conditions for the user equipment 30. In other words, the radio conditions processor 28 obtains data associated with estimated radio conditions for the user equipment 30. In a basic version, the estimated radio conditions could e.g. comprise two flags, one indicating low or high Doppler shift and one indicating small or large delay spread. When having a radio resource space in frequency and time dimensions, quantities associated with coherence bandwidth and coherence time, respectively, are of interest. The estimated radio conditions

are forwarded to the pilot manager 26, which performs the actual selection and/or adjustment of resource sub-spaces. The pilot manager 26 thus provides access to the use of the different pilot configurations. When pre-defined pilot patterns are used, the pilot manager selects in which part of the multi-carrier space the allocated resource sub-space will be placed. Without pre-defined patterns in different parts of the multi-carrier space, the pilot manager 26 comprises functionalities for selecting a multi-carrier sub-space for allocation and functionalities to adapt the pilot pattern of that selected sub-space according to the estimated radio conditions. When the pilot manager has decided what pilot pattern to apply, the user equipment 30 has to be informed about the selection, in order to be able to perform the right channel estimation upon reception of the data. The pilot manager 26 thus comprises means for transferring suitable data to the channel estimator 36.

In Fig. 9B, another embodiment is illustrated, where the base station 20 has the entire responsibility for the selection of pilot structure. The downlink control unit 25 here also comprises a position estimator 29. The position estimator 29 provides an estimation of the position of the user equipment 30 and preferably also the velocity. This can be performed in any manner, e.g. according to prior art methods, and is not further discussed here. The position is forwarded to the radio condition processor 28. The radio condition processor 28 has access to knowledge about the different environments within the cell. A cell could e.g. cover a first area having generally slowly moving user equipments, and a second area, where the average speed is considerably higher. The position estimation could reveal the location of the user equipment, i.e. if it is situated in the high- or low-speed area. From such information, the radio condition processor 28 can conclude what radio conditions that should be assumed for the user equipment. Such estimation then forms the base on which the pilot pattern is selected.

In Fig. 9C, yet another embodiment is illustrated. In this embodiment, the user equipment 30 makes more efforts in the procedure to find suitable pilot structures. The downlink control unit 35 here additionally comprises a radio

conditions processor 39. This means that both the measurements and the evaluation of the measurements are performed in the user equipment 30. The estimated radio conditions are reported to the base station 20, e.g. in the form of data representing coherence bandwidth and coherence time, respectively. Alternatively, the radio conditions processor 39 can also select an appropriate pilot pattern and transmit a request to use such a pattern to the base station 20. The base station 20 can in such a case either follow the recommendation or overrule it and make an own decision.

Fig. 10 illustrates one possible configuration for uplink communication. The base station 20 comprises an uplink control unit 45, in turn comprising a radio conditions measurement unit 21, a radio conditions processor 28 and a pilot manager 26. The operations of the units are similar to the ones in the downlink case, but adapted for uplink communication instead, i.e. it is the radio conditions of the received signals from the user equipment 30 that are of importance. The pilot manager 26 decides which pilot pattern that is appropriate to apply, and transmits a request to an uplink control unit 55 in the user equipment 30. In a basic version, the uplink control unit 55 simply applies the proposed pilot pattern on its uplink traffic. The uplink control unit 35 of the base station 20 also comprises a channel estimator 27 in order to be able to detect the data sent on the uplink. This channel estimator 27 is also informed about the pilot structure to use.

Fig. 11 illustrates yet another embodiment of the present invention, in which one makes use of the possibilities to vary the intensity to reduce pilot pollution. In parts 110A and 110D, all or some of the pilot data is marked to be transmitted with a lower (or zero) intensity. If a user equipment using the pilot signals is close to the base station, the transmission power does not have to be equally high to obtain a reasonable channel estimation compared with user equipments situated further away from the base station. In such a way, it is also possible to vary the pilot intensity throughout the resource space. Such intensity configurations can as above be performed either in advance or as adjustment procedures.



The pilot symbols can also be transmitted with different power for different classes of users and depending on path loss. The power levels can either be dynamically varying between zero and a given number  $P_{\max}$  or be defined in advance. Note that a power level equal to zero is equivalent to no pilots for this slot, enabling the use of this slot for other purposes, such as data. If the power is dynamically varying, the power levels have to be signalled to the receiver for appropriate treatment.

When there are several possible pilot patterns to use in a system, the receiver has to be informed about which one is actually used. If a numbered set of pre-determined pilot patterns are used, the identification number of the pilot pattern is sufficient. However, more elaborate systems can use different pilot patterns for different cells and the numbering of patterns can be difficult to manage. In such a case, a solution is to transfer a complete description of the pilot pattern to be used. For regular pilot patterns, the amount of data that is needed to uniquely define the patterns is quite limited.

In Fig. 12, a pilot pattern is illustrated within a resource sub-space in frequency and time dimensions. The resource sub-space is reported anyway, and is typically defined by frequency and time "coordinates" and the number of frequency DF and time DT slots that are comprised in the sub-space. The pilot pattern is then easily characterised by only three vectors in the (two-dimensional) resource space. A first vector V0 defines the "distance" in frequency and time, respectively, between a well-defined position in the sub-space, e.g. the lower left corner as illustrated in the picture, and any pilot data within the pattern. A second vector V1 defines a "relative distance" between the two closest pilots in the pattern. A third vector V2 defines a "relative distance" between the second closest pilots, that is not aligned with the first vector V1. By knowing only these vectors, the entire pilot pattern can easily be calculated.

Also somewhat more complicated patterns can be fit into a similar model. In Fig. 13, a pattern having two neighbour pilots distributed in pairs over the resource space. In order to describe this pattern, only one extra vector is needed, the relative vector between the two pilots in each pair. Anyone skilled in the art realises that with a very limited number of data, rather complex pilot patterns can easily be defined.

It will be understood by those skilled in the art that various modifications and changes may be made to the present invention without departure from the scope thereof, which is defined by the appended claims.